Demonstration of ISCO Treatment of a DNAPL Source Zone at Launch Complex 34 in Cape Canaveral Air Station

Final Innovative Technology Evaluation Report

Prepared for

The Interagency DNAPL Consortium:

U.S. Department of Energy
U.S. Environmental Protection Agency
U.S. Department of Defense
National Aeronautics and Space Administration

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Appendix H

Economic Analysis Information

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This appendix details the cost assessment for the application of the pump and treat (P&T) system for containment of a DNAPL source at Launch Complex 34, for a source zone that is the same size as the ISCO plot. Because the groundwater flow in this area is generally to the northeast, the DNAPL source could be contained by installing one cluster (of 3 in each lithologic unit) or more extraction wells on the northeast side of the ISCO plot. The life cycle cost of a pump-and-treat system can be compared to the cost of DNAPL source removal using chemical oxidation, as described in Section 7 of the main report.

Experience at previous sites indicates that the most efficient long-term P&T system is one that is operated at the minimum rate necessary to contain a plume or source zone (Cherry et al., 1996). Table H-1 shows a preliminary size determination for the P&T system. The P&T system should be capable of capturing the groundwater flowing through a cross-section that is approximately 50 ft wide (width of ISCO plot) and 40 ft deep (thickness of surficial aquifer). Because capture with P&T systems is somewhat inefficient in that cleaner water from surrounding parts of the aquifer may also be drawn in, an additional safety factor of 100% was applied to ensure that any uncertainties in aquifer capture zone or DNAPL source characterization are accounted for. An extraction rate of 2 gallon per minute (gpm) is found to be sufficient to contain the source.

One advantage of low groundwater extraction rates is that the air effluent from stripping often does not have to be treated, as the rate of volatile organic compound (VOC) discharge to the ambient air is often within regulatory limits. The longer period of operation required (at a low withdrawal rate) is more than offset by higher efficiency (lower influx of clean water from outside the plume), lower initial capital investment (smaller treatment system), and lower annual operations and maintenance (O&M) requirements. Another advantage of a containment type P&T system is that, unlike source removal technologies, it does not require very extensive DNAPL zone characterization.

H.1.1 Capital Investment for the P&T System

The P&T system designed for this application consists of the components shown in Table H-2. Pneumatically driven pulse pumps, which are used in each well, are safer than electrical pumps in the presence of trichloroethylene (TCE) vapors in the wells. This type of pump can sustain low flowrates during continuous operation. Stainless steel and Teflon™ construction ensure compatibility with the high concentrations (up to 1,100 mg/L TCE) of dissolved solvent and any free-phase DNAPL that may be expected. Extraction wells are assumed to be 40 ft deep, 2 inches in diameter, and have stainless steel screens with polyvinyl chloride (PVC) risers.

The aboveground treatment system consists of a DNAPL separator and air stripper. Very little free-phase solvent is expected and the separator may be disconnected after the first year of operation, if desired. The air stripper used is a low-profile tray-type air stripper. As opposed to conventional packed towers, low-profile strippers have a smaller footprint, much smaller height, and can handle large air:water ratios (higher mass transfer rate of contaminants) without generating significant pressure losses. Because of their small size and easy installation, they are more often used in groundwater remediation. The capacity of the air stripper selected is much higher than 2 gpm, so that additional flow (or additional extraction wells) can be handled if required.

The high air:water ratio ensures that TCE (and other minor volatile components) are removed to the desired levels. The treated water effluent from the air stripper is discharged to the sewer. At the low groundwater extraction rate required, the resulting contaminant mass in the air effluent from the stripper is less than 2 lbs/day, and below a typical regulatory limit of 6 lbs/day. The air effluent can be discharged without further treatment.

The piping from the wells to the air stripper is run through a 1-ft-deep covered trench. The air stripper and other associated equipment are housed on a 20-ft-x-20-ft concrete pad, covered by a basic shelter. The base will provide a power drop (through a pole transformer) and a licensed electrician will be used for the power hookups. Meters and control valves are strategically placed to control water and air flow through the system.

The existing monitoring system at the site will have to be supplemented with seven long-screen (10-foot screen) monitoring wells. The objective of these wells is to ensure that the desired containment is being achieved.

H.1.2 Annual Cost of the P&T System

The annual costs of P&T are shown in Table H-3 and include annual operation and maintenance (O&M) and monitoring. Annual O&M costs include the labor, materials, energy, and waste disposal cost of operating the system and routine maintenance (including scheduled replacement of seals, gaskets, and O-rings). Routine monitoring of the stripper influent and effluent is done through ports on the feed and effluent lines on a monthly basis. Groundwater monitoring is conducted on a quarterly basis through seven monitoring wells. All water samples are analyzed for PCE and other chlorinated volatile organic compound (CVOC) by-products.

H.1.3 Periodic Maintenance Cost

In addition to the routine maintenance described above, periodic maintenance will be required, as shown in Table H-3, to replace worn-out equipment. Based on manufacturers' recommendations for the respective equipment, replacement is done once in 5 or 10 years. In general, all equipment involving moving parts is assumed will be replaced once every 5 years, whereas other equipment is changed every 10 years.

H.1.4 Present Value (PV) Cost of P&T

Because a P&T system is operated for the long term, a 30-year period of operation is assumed for estimating cost. Because capital investment, annual costs, and periodic maintenance costs occur at different points in time, a life cycle analysis or present value analysis is conducted to estimate the long-term cost of P&T in today's dollars. This life cycle analysis approach is recommended for long-term remediation applications by the guidance provided in the Federal Technologies Roundtable's *Guide to Documenting and Managing Cost and Performance Information for Remediation Projects* (United States Environmental Protection Agency [U.S. EPA], 1998). The PV cost can then be compared with the cost of faster (DNAPL source reduction) remedies.

$$PV_{\text{P\&T costs}} = \sum \frac{\text{Annual Cost in Year t}}{(1 + r)^t} \qquad \text{Equation (H-1)}$$

$$PV_{\text{P\&T costs}} = \text{Capital Investment} + \frac{\text{Annual cost in Year 1}}{(1+r)^1} + \ldots + \frac{\text{Annual cost in Year n}}{(1+r)^n}$$

Equation (H-2)

Table 4 shows the PV calculation for P&T based on Equation 1. In Equation 1, each year's cost is divided by a discount factor that reflects the rate of return that is foregone by incurring the cost. As seen in Equation 2, at time t = 0, which is in the present, the cost incurred is the initial capital investment in equipment and labor to design, procure, and build the P&T system. Every year after that, a cost is incurred to operate and maintain the P&T system. A real rate of return (or discount rate), r, of 2.9% is used in the analysis as per recent U.S. EPA guidance on discount rates (U.S. EPA, 1999). The total PV cost of purchasing, installing, and operating a 1-gpm P&T source containment system for 30 years is estimated to be **$1,406,000** (rounded to the nearest thousand).

Long-term remediation costs are typically estimated for 30-year periods as mentioned above. Although the DNAPL source may persist for a much longer time, the contribution of costs incurred in later years to the PV cost of the P&T system is not very significant and the total 30-year cost is indicative of the total cost incurred for this application. This can be seen from the fact that in Years 28, 29, and 30, the differences in cumulative PV cost are not as significant as the difference in, say, Years 2, 3, and 4. The implication is that, due to the effect of discounting, costs that can be postponed to later years have a lower impact than costs that are incurred in the present.

As an illustration of a DNAPL source that may last much longer than the 30-year period of calculation, Figure H-1 shows a graphic representation of PV costs assuming that the same P&T system is operated for 100 years instead of 30 years. The PV cost curve flattens with each passing year. The total PV cost after 100 years is estimated at $2,195,000.

Table H-1. Pump & Treat (P&T) System Design Basis for Site 88 DNAPL Zone at Camp

Item	Value	Units	Item	Value	Units
Width of DNAPL zone, w	50	ft	Hyd. conductivity, K	40	ft/d
Depth of DNAPL zone, d	40	ft	Hyd. gradient, I	0.0007	ft/ft
Crossectional area of DNAPL zone, a	2000	sq ft	Porosity, n	0.3	
Capture zone required	187	cu ft/d	Gw velocity, v	0.093333	ft/d
Safety factor, 100%	2				
Required capture zone	373	cu ft/d	GPM =	1.9	gpm
Design pumping rate	2	gpm	Number of wells to achieve capture	1	
Pumping rate per well	2	gpm			
TCE conc. in water near DNAPL zone	100	mg/L	TCE allowed in discharge water	1	mg/L
Air stripper removal efficiency required	99.00%				
TCE in air effluent from stripper	2.4	lbs/day	TCE allowed in air effluent	6	lbs/day

Table H-2. Capital Investment for a P&T System at Launch Complex 34, Cape Canaveral

Item	# units		Unit Price	Cost	Basis
Design/Procurement					
Engineer	160	hrs	$85	$13,600	
Drafter	80	hrs	$40	$3,200	
Hydrologist	160	hrs	$85	$13,600	
Contingency	1	ea	$10,000	$10,000	10% of total capital
TOTAL				$30,400	
Pumping system					
Extraction wells	1	ea	$5,000	$5,000	2-inch, 40 ft deep, 30-foot SS screen; PVC; includes installation
Pulse pumps	1	ea	$595	$595	2.1 gpm max., 1.66"OD for 2-inch wells; handles solvent contact; pneumatic; with chec valves
Controllers	1	ea	$1,115	$1,115	Solar powered or 110 V; with pilot valve
Air compressor	1	ea	$645	$645	100 psi (125 psi max), 4.3 cfm continuous duty, oil-less; 1 hp
Miscellaneous fittings	1	ea	$5,000	$5,000	Estimate
Tubing	150	ft	$3	$509	1/2-inch OD, chemical resistant; well to surface manifold
TOTAL				$12,864	
Treatment System					
Piping	150	ft	$3	$509	chemical resistant
Trench	1	day	$320	$320	ground surface
DNAPL separarator tank	1	ea	$120	$120	125 gal; high grade steel with epoxy lining; conical bottom with discharge
Air stripper feed pump	1	ea	$460	$460	0.5 hp; up to 15 gpm
Piping	50	ft	$3	$170	0.5 inch, chemical resistant; feed pump to stripper
Water flow meter	1	ea	$160	$160	Low flow; with read out
Low-profile air stripper with control panel	1	ea	$9,400	$9,400	1-25 gpm, 4 tray; SS shell and trays
Pressure gauge	1	ea	50	$50	SS; 0-30 psi
Blower	1	ea	$1,650	$1,650	5 hp
Air flow meter	1	ea	$175	$175	Orifice type; 0-50 cfm
Catalytic Oxidizer	1	ea	$65,000	$65,000	
Stack	10	ft	$2	$20	2 inch, PVC, lead out of housing
Carbon	2	ea	$1,000	$2,000	
Stripper sump pump	1	ea	$130	$130	To sewer
Misc. fittings, switches	1	ea	$5,000	$5,000	Estimate (sample ports, valves, etc.)
TOTAL				$85,163	
Site Preparation					
Conctrete pad	400	sq ft	$3	$1,200	20 ft x 20 ft with berm; for air stripper and associated equipment
Berm	80	ft	$7	$539	
Power drop	1	ea	$5,838	$5,838	230 V, 50 Amps; pole transformer and licensed electrician
Monitoring wells	5	wells	$2,149	$10,745	Verify source containment; 2-inch PVC with SS screens
Sewer connection fee	1	ea	$2,150	$2,150	
Sewer pipe	300	ft	$10	$3,102	
Housing	1	ea	$2,280	$2,280	20 ft x 20 ft; shelter for air stripper and associated equipment
TOTAL				$25,854	
Installation/Start Up of Treatment System					
Engineer	60	hrs	$85	$5,100	Labor
Technician	200	hrs	$40	$8,000	Labor
TOTAL				$13,100	
TOTAL CAPITAL INVESTMENT				**$167,381**	

Table H-2. Capital Investment for a P&T System at Launch Complex 34, Cape Canaveral (continued)

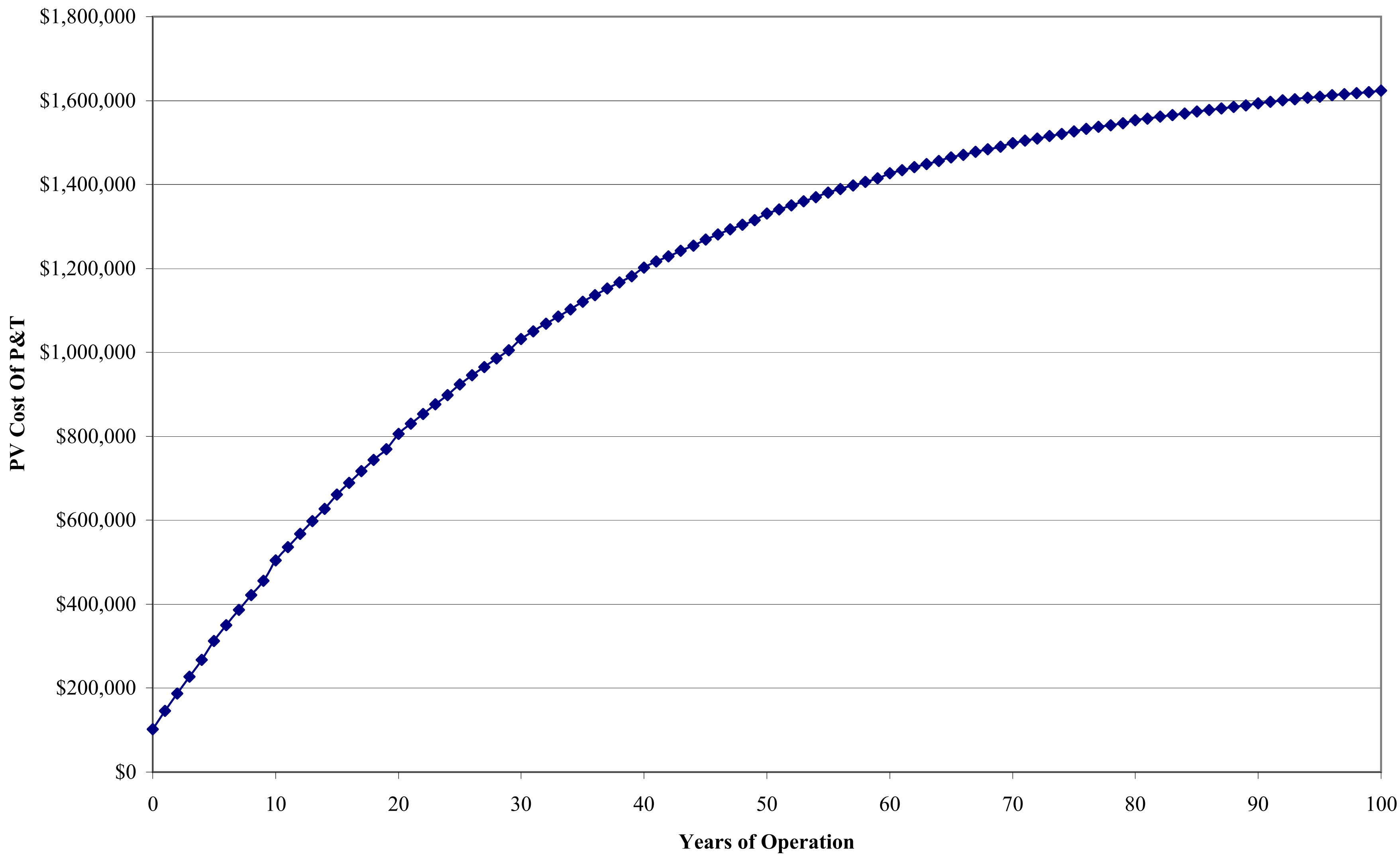
O&M Cost for P&T Sytem					
Annual Operation & Maintenance					
Engineer	80	hrs	$85	$6,800	Oversight
Technician	500	hrs	$40	$20,000	Routine operation; annual cleaning of air stripper trays, routine replacement of parts; any waste disposal
Replacement materials	1	ea	$2,000	$2,000	Seals, o-rings, tubing, etc.
Electricity	52,560	kW-hrs	$0.10	$5,256	8 hp (~6 kW) over 1 year of operation
Fuel (catlytic oxidizer	2,200	10M BTU	$6	$13,200	
Sewer disposal fee	525,600	gal/yr	$0.00152	$799	
Carbon disposal	2		$1,000	$2,000	
Waste disposal	1	drum	$80	$200	30 gal drum; DNAPL, if any; haul to incinerator
TOTAL				**$50,255**	
Annual Monitoring					
Air stripper influent	12	smpls	$120	$1,440	Verify air stripper loading; monthly
Air stripper effluent	14	smpls	$120	$1,680	Discharge quality confirmation; monthly; CVOC analysis; MS, MSD
Monitoring wells	34	smpls	$120	$4,080	5 wells; quarterly; MS, MSD
Sampling materials	1	ea	$500	$500	Miscellaneous
Technician	64	hrs	40	$2,560	Quarterly monitoring labor (from wells) only; weekly monitoring (from sample ports) included in O&M cost
Engineer	40	hrs	85	$3,400	Oversight; quarterly report
TOTAL				$7,200	
TOTAL ANNUAL COST				**$57,455**	
Periodic Maintenance, Every 5 years					
Pulse pumps	4	ea	$595	$2,380	As above
Air compressor	1	ea	$645	$645	As above
Air stripper feed pump	1	ea	$460	$460	As above
Blower	1	ea	$1,650	$1,650	As above
Catalyst replacement	1	ea	$5,000	$5,000	
Stripper sump pump	1	ea	$130	$130	As above
Miscellaneous materials	1	ea	$1,000	$1,000	Estimate
Technician	40	hrs	$40	$1,600	Labor
TOTAL				**$12,865**	
				$70,320	
Periodic Maintenance, Every 10 years					
Air stripper	1	ea	$9,400	$9,400	As above
catalytic oxidizer	1	ea	$16,000	$16,000	Major overhaul
Water flow meters	1	ea	160	$160	As above
Air flow meter	1	ea	175	$175	As above
Technician	40	hrs	$40	$1,600	Labor
Miscellaneous materials	1	ea	$1,000	$1,000	Estimate
TOTAL				**$28,335**	
TOTAL PERIODIC MAINTENANCE COSTS				**$98,655**	

Table H-3. Present Value of P&T System Costs for 30 years of operation

Year	P&T		
	Annual Cost *	PV of Annual Cost	Cumulative PV of Annual Cost
0	**$167,381**	$167,381	$167,381
1	$57,455	$55,836	$223,217
2	$57,455	$54,262	$277,479
3	$57,455	$52,733	$330,212
4	$57,455	$51,247	$381,459
5	**$70,320**	$60,954	$442,413
6	$57,455	$48,399	$490,811
7	$57,455	$47,035	$537,846
8	$57,455	$45,709	$583,556
9	$57,455	$44,421	$627,977
10	**$98,655**	$74,125	$702,102
11	$57,455	$41,953	$744,054
12	$57,455	$40,770	$784,825
13	$57,455	$39,621	$824,446
14	$57,455	$38,505	$862,951
15	**$70,320**	$45,798	$908,749
16	$57,455	$36,365	$945,114
17	$57,455	$35,340	$980,454
18	$57,455	$34,344	$1,014,798
19	$57,455	$33,376	$1,048,174
20	**$98,655**	$55,694	$1,103,868
21	$57,455	$31,521	$1,135,389
22	$57,455	$30,633	$1,166,022
23	$57,455	$29,770	$1,195,792
24	$57,455	$28,931	$1,224,723
25	**$70,320**	$34,411	$1,259,134
26	$57,455	$27,323	$1,286,457
27	$57,455	$26,553	$1,313,010
28	$57,455	$25,805	$1,338,814
29	$57,455	$25,077	$1,363,892
30	**$98,655**	$41,846	$1,405,738

* Annual cost in Year zero is equal to the capital investment.
Annual cost in other years is annual O&M cost plus annual monitoring cost
Annual costs in Years 10, 20, and 30 include annual
O&M, annual monitoring, and periodic maintenance

Figure H-1. P&T System Costs - 100 years



Appendix I

Technical Information for $KMnO_4$ Used for the ISCO Demonstration

CAIROX®

Potassium Permanganate

CAS Registry No. 7722-64-7

Free-Flowing Grade

Free-Flowing Grade is recommended where potassium permanganate is subjected to high humidity conditions and where the material is to be dry fed through a chemical feeder or stored in a bin or hopper.

Free-Flowing Grade

Assay
Guaranteed 97% $KMnO_4$

Particle Size
20% maximum retained on #425 U.S. Standard Sieve (formerly #40)
7% maximum through #75 U.S. Standard Sieve (formerly #200)

Standards and Specifications
CAIROX® Potassium Permanganate is certified by the National Sanitation Foundation (NSF) to ANSI/NSF Standard 60: Drinking Water Treatment Chemicals - Health Effects.

Technical Grade meets:
- AWWA Standard B603
- Military Specifications MIL-P-11970-C dated 14 October 1983
- Water Chemical Codex RMIC values

Chemical/Physical Data

Formula	$KMnO_4$
Formula Weight	158.0 g/mol
Form	Granular Crystalline
Specific Gravity	
Solid	2.703 g/cm^3
3% Solution	1.020 g/mL by weight, 20°C / 4°C
Bulk Density	Approximately 100 lb/ft^3

Decomposition may start at 150 °C / 302 °F

Solubility in Distilled Water

Temperature		Solubility	
°C	°F	g/L	oz/gal
0	32	27.8	3.7
20	68	65.0	8.6
40	104	125.2	16.7
60	140	230.0	30.7
70	158	286.4	38.3
75	167	323.5	43.2

For more information, refer to the *Solubility Fact Sheet*.

Shipping Containers

25 kg pail[1] (55.125 lb) net, with handle, made of HDPE, weighs 3.1 lb. It is tapered to allow nested storage of empty drums, stands approximately 15½ inches high and has a maximum diameter of 12 inches.

150 kg drum[1] (330.750 lb) net, made of 22-gauge steel, weighs 22.4 lbs. It stands approximately 29½ inches high and is approximately 19¾ inches in diameter.

1500 kg Cycle-Bin™[2] (3307 lb) net.

Bulk, up to 48,000 lbs.

Special Packages will be considered on request.

(1) Meets UN performance oriented packaging requirements.
(2) The Cycle-Bin™ meets DOT 56 Specifications.

Description

Crystals or granules are dark purple with a metallic sheen, sometimes with a dark bronze-like appearance. Free-Flowing Grade is gray due to an additive. Potassium permanganate has a sweetish, astringent taste and is odorless.

Handling, Storage, and Incompatibility

Protect containers against physical damage. When handling potassium permanganate, respirators should be worn to avoid irritation of or damage to mucous membranes. Eye protection should also be worn when handling potassium permanganate as a solid or in solution.

Potassium permanganate is stable and will keep indefinitely if stored in a cool, dry area in closed containers. Concrete floors are preferred to wooden decks. To clean up spills and leaks, follow the steps recommended in the MSDS. Be sure to use goggles, rubber gloves, and respirator when cleaning up a spill or leak.

Avoid contact with acids, peroxides, and all combustible organic or readily oxidizable materials including inorganic oxidizable materials and metal powders. With hydrochloric acid, chlorine gas is liberated. Potassium permanganate is not combustible, but will support combustion. It may decompose if exposed to intense heat. Fires may be controlled and extinguished by using large quantities of water. Refer to the *MSDS* for more information.

Corrosive Properties

Potassium permanganate is compatible with many metals and synthetic materials. Natural rubbers and fibers are often incompatible. Solution pH and temperature are also important factors. The material must be compatible with either the acid or alkali also being used.

In neutral and alkaline solutions, potassium permanganate is not corrosive to iron, mild steel, or stainless steel; however, chloride corrosion of metals may be accelerated when an oxidant such as permanganate is present in solution. Plastics such as polypropylene, polyvinyl chloride Type I (PVC I), epoxy resins, fiberglass reinforced plastic (FRP), Penton, Lucite, Viton A, and Hypalon are suitable. Teflon FEP and TFE, and Tefzel ETFE are best. *Refer to Material Compatibility Chart*.

Aluminum, zinc, copper, lead, and alloys containing these metals may be (slightly) affected by potassium permanganate solutions. Actual studies should be made under the conditions in which permanganate will be used.

Shipping

Potassium permanganate is classified by the Hazardous Materials Transportation Board (HMTB) as an oxidizer. It is shipped under Interstate Commerce Comission's (ICC) Tariff 19.

Proper Shipping Name:	Potassium Permanganate (RQ-100/45.4)
Hazard Class:	Oxidizer
Identification Number:	UN 1490
Label Requirements:	Oxidizer
Packaging Requirements:	49 CFR Parts 100 to 199, Sections: 173.152, 173.153, 173.194

Shipping Limitations:

Minimum quantities:

Rail car: See Tariff for destination
Truck: No minimum

Postal regulations:

Information applicable to packaging of oxidizers for shipment by the U.S. Postal Service to domestic and foreign destinations is readily available from the local postmaster.

United Parcel Service accepts 25 lbs as largest unit quantity properly packaged; consult United Parcel Service.

Regulations concerning shipping and packing should be consulted regularly due to frequent changes.

Repacking

When potassium permanganate is repacked, the packing, markings, labels, and shipping conditions must meet applicable Federal regulations. See Code of Federal Regulations-49, Transportation (parts 100-199) and Federal Hazardous Materials Substances Act, 15 U.S.C. 1261.

Applications

Listed below are some of the many applications of potassium permanganate. Permanganate is a powerful oxidizing agent. The optimum condition under which it is to be used can be easily established through technical service evaluations or laboratory testing.

Oxidation and Synthesis - Organic chemicals and intermediates manufacture. Oxidizes impurities in organic and inorganic chemicals.

Water Treatment - Oxidizes iron, manganese, and hydrogen sulfide; controls taste and odor; and is an alternate pre-oxidant for Disinfection By-Product (THMs and HAAs) control.

Municipal Wastewater Treatment - Destroys hydrogen sulfide in wastewater and sludge. Improves sludge dewatering.

Industrial Wastewater Treatment - Oxidizes hydrogen sulfide, phenols, iron, manganese, and many other organic and inorganic contaminants; resultant manganese dioxide aids in removing heavy metals.

Metal Surface Treatment - Conditions mill scale and smut to facilitate subsequent removal by acid pickling in wrought metals manufacturing and jet engine cleaning.

Equipment Cleaning - Assists in cleaning organic and inorganic residues from refining and cooling towers and other processing equipment. Decontaminates hydrogen sulfides, pyrophoric iron sulfides, phenols, and others.

Purification of Gases - Removes trace impurities of sulfur, arsine, phosphine, silane, borane, and sulfides from carbon dioxide and other industrial gases.

Mining and Metallurgical - Aids in separation of molybdenum from copper; removes impurities from zinc and cadmium; oxidizes flotation compounds. Removes iron and manganese from acid mine drainage.

Hazardous Waste Treatment or Remediation - Treats phenols, chlorinated solvents (TCE, PCE), tetraethyl lead, chelated metals, cyanides, and sulfides.

Slag Quenching - Controls hydrogen sulfide and acetylene emissions during quenching of hot slag.

Food Processing - Controls sulfides, soluble animal oil, grease, organic acids, ketones, nitrogen compounds, mercaptans, and BOD.

Carus Chemical Company
315 Fifth Street
P. O. Box 599
Peru, IL 61354
Tel. (815) 223-1500
Fax (815) 224-6697
Web: www.caruschem.com
E-Mail: salesmkt@caruschem.com

CARUS

Responsible Care®
Good Chemistry at Work

CARUS

CAIROX® POTASSIUM PERMANGANATE

GRADE: FREE FLOW

COMPOSITE ANALYSIS

(Based on July 1998 20 Lot Composite)

PARAMETER	COMPOSITE ANALYSIS
Insolubles, %	0.44
Wt. Loss (105° C), %	0.16
pH, 5% Solution	9.59
Chloride, %	0.0070
Sulfate, %	0.0200
Nitrogen, %	0.0020
Sieve Analysis, % on:	
U.S. Std. No. 40 (420μm)	0.2
U.S. Std. No. 60 (250μm)	28.9
U.S. Std. No. 80 (177μm)	27.3
U.S. Std. No. 100 (149μm)	22.9
U.S. Std. No. 140 (105μm)	15.6
U.S. Std. No. 200 (74μm)	3.1
U.S. Std. No. -200 (74μm)	2.0

Metals (mg/Kg):

Aluminum	61.6	Lithium	10.6
Antimony	0.8	Magnesium	2.2
Arsenic	3.3	Mercury	0.05
Barium	11.1	Molybdenum	7.9
Beryllium	<0.8	Nickel	4.2
Bismuth	0.8	Phosphorus	3.2
Boron	4.6	Selenium	0.1
Cadmium	0.4	Silicon	2800.0
Calcium	43.3	Silver	<0.8
Chromium	10.0	Sodium	304.0
Cobalt	1.2	Strontium	<0.4
Copper	25.3	Thallium	3.4
Iron	24.7	Vanadium	11.6
Lead	1.4	Zinc	3.8

Note: Material conforms to ANSI/NSF Standard 60.